Robotic Autonomy for Space: closely coordinated control of networked robots

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Significant recent progress has been made in supervisory automation of robots for space applications, including such activities as planetary surface exploration by rovers. Examples at the author's home institution include Rocky7, FIDO rover, and others. However, there remain significant challenges in several areas that include autonomous navigation & planning, fault tolerant operations, and multi-robot cooperation. We report our ongoing work in the last area, for which we are developing approaches to the robust and extensible coordination of closely cooperating mobile platforms. "Closely cooperating," signifies not only time-and-communication synchronized action, but also operations under strong shared non-holonomic constraints. While we are addressing both space (Schenker) and terrestrial (McKee) applications, the primary focus of this work is Mars exploration, for which we have implemented working autonomy architectures and conceptual demonstrations of novel robotic tasks (cf. "CAMPOUT"/JPL and "NETROLab"/UReading). In particular, we recently conducted first of kind experimentation in which two agile rovers carry out kinematics-and-force-constrained cooperative manipulation and transport of large, extended payloads over natural terrain. This has space applications to deployment of large surface science instrumentation, in-field science/sample-transfers, future robotic outpost developments, on-orbit assembly, etc. The underlying basis is a new hybrid behavioral/deliberative control architecture for multi-robot environments. Sensor-based controls at lower levels are derived as "primitive" behaviors and composed at higher levels as group "coordinated" behaviors—in essence a behavior-based control hierarchy. Examples at lower level include such functions as inter-rover velocity syncing, relative position coordination by visual track-and-follow, inter-rover payload handling compliance and, at higher levels, the autonomous visual guidance, cooperative formation (e.g., "row" or "column" based traverse) and visual staging and cooperative mobility for approach and rendezvous to a target site. We will describe this multi-robot autonomous control architecture in some depth, describe some implementation examples of some of its key behavior-based functions, and comprehensively contrast-and-compare it with other related architectures.

Complementing this work, McKee and Schenker are developing a related construct for "networked robotics" as pertains to resource utilization and modular reconfiguration. This has importance for several applications areas that include distributed/"Internet" robotic systems, flexible factory floor manufacture, and notably, sustainable space robotic environments. The essence of networked robotics is the concept of distributed resources that provide one or more interactive services. Sensors (vision, range, position), effectors (manipulators, mechatronic modules, grippers, mobile platforms) and computational units (fused state estimation, mapping, planning and navigation-control functions) are three basic categories of resource encountered in robotics. In conventional robot architectures, resources are not distinguished as such; sensors, effectors, and computational units are often "hard-wired" components of a fixed, immutable algorithm, the control architecture. Networked robotics recognizes these functional units, enhances them with an interface that makes explicit services they can export, and incorporates scope for a range of local and remote connectivity options. The resources, now encapsulated as independent modules, provide the basis *for flexible reconfigurable robot architectures that can span multiple physical robot systems, namely a networked robot.* Higher-level networked modules can in principle autonomously inherit attributes of lower-level resources, with emergent control and sensing properties, and accompanying new descriptors. The three basic elements of a general networked robotics system are a set of resources, a configuration definition specifying the topology and connectivity of the modules, and a name server holding location information for the resources. The benefits of networked robotics thus lie in the ability to distribute, relocate and reconfigure set of resources arrayed across multiple physical mobile robot platforms into single or multiple cooperating robot systems, many properties of which are synergistic with the generalization of the above CAMPOUT implementation. We will overview these developments, including some of the key open research issues.

References

[1] P. S. Schenker and G. T. McKee, "Man-machine interaction in telerobotic systems and issues in the architecture of intelligent and cooperative control," in Proc. IEEE/Intl. Symp. Intelligent Control Workshop (Architectures for Semiotic Modeling and Situation Analysis in Large Complex Systems, Orgs.: J. Albus, A. Meystel, D. Pospelov, T. Reader), 12 pp., Monterey, CA, August, 1995.

[2] P. S. Schenker, T. L. Huntsberger, P. Pirjanian, A. Trebi-Ollennu, H. Das, S. Joshi, H. Aghazarian, B. A. Kennedy, A. J. Ganino, and M. S. Garrett, "Robot work crews for planetary outposts: close cooperation and coordination of multiple mobile robots," Proc. SPIE Vol. 4196, Sensor Fusion and Decentralized Control in Robotic Systems III (Eds. G. T. McKee and P. S. Schenker), 11 pp., Boston, MA, Nov. 5-8, see also, 2000; P. Pirjanian, T.L. Huntsberger, A. Trebi-Ollennu, H. Aghazarian, H. Das, S. Joshi, and P.S. Schenker, "CAMPOUT: A control architecture for multi-robot planetary outposts," ibid.

[3] G. T. McKee and P. S. Schenker, "Networked robotics," ibid; G. T. McKee and B. Brooks, "Resource management for networked robotics systems, Proc. IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS '97), Vol. 3, pp. 1363-1368, 1997; J. A. Fryer, G. T. McKee and P. S. Schenker, "Configuring robots from modules: an object oriented approach," 8th Intl. Conf. on Advanced Robotics (ICAR '97), Monterey, California, July 7-9, pp 907-912, 1997.

Author Biography

Dr. Paul S. Schenker is Supervisor, Mechanical and Robotics Technologies Group, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, wherein he leads R&D in the areas of surface robotic mobility, sampling and advanced actuation. His current research focuses on development of autonomous rover based science and sample return, including new concepts in multiple rover cooperation and reconfigurable mobile systems for all terrain exploration. Recent examples include JPL's FIDO rover, Sample Return Rover, MarsArm (Mars Polar Lander R&D prototype), and Robot Assisted Microsurgery System. His research specializations include machine perception, sensor fusion, advanced robotic control, and intelligent user interfaces, in which he has authored about 100 peer reviewed publications. Dr. Schenker is a Fellow and the Immediate Past President of SPIE (1999).